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Deciphering tectonic, climatic-induced and hydrothermal signals in the late-stage exhumation history of the upper Rhône valley (Swiss Alps)

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Neogene exhumation of the European Alps is understood as the interplay between tectonics and climatic-induced erosion. While the former has been influenced by a decrease in plate convergence, the latter has been suggested to be affected by climatic variation and the onset of Plio-Quaternary glaciations, leading to relief amplification. However, even though geomorphologic and sedimentologic studies both suggest topographic relief change and transition from fluvial to oscillations between glacial/fluvial conditions, precise quantification on both the timing and magnitude of this transition are yet sparse.

Our study focuses on the upper Rhône valley (Swiss Central Alps) within the Visp-Brig area (Aar massif). This area encompasses some of the most spectacular reliefs within the Alps with several nearby summits around or above 4000 m crosscut by the glacially overdeepened Rhône valley. It also shows among the highest late Neogene exhumation rates within the Western-Central European Alps, influenced by tectonic activity along the major Simplon-Rhône extensional fault system. Moreover, the upper Rhône valley has experienced enhanced glacial erosion associated with strong relief development during the Pliocene-Quaternary period. Finally, structural inheritance, late-stage tectonics and rapid exhumation may have promoted recent hydrothermal activity in this region, although timing of its onset and its precise causes remain poorly understood. We investigated the late-stage cooling history by using different low-temperature thermochronometers along a pseudo-vertical bedrock profile (elevation between 600 and 2900 m) and additional samples from an on-site 500-m geothermal well, resulting in a total elevation difference of nearly 3 km. Apatite fission-track (AFT) ages and track-length data have been added to previously published and new apatite (U-Th-Sm)/He (AHe) and 4He/3He data.

Our results confirm high-exhumation rates (0.6 to 0.9 km/Myr) within late-Cenozoic to Pliocene times. Combined with AFT data from the literature, our age pattern reveals no exhumation difference across the Simplon fault system during the last 6-8 Ma, suggesting only strike-slip detachment activity of the structure during that period. Thermal modelling using HeFTy confirms rapid exhumation and evidences a late-stage cooling contrast between high-elevation and valley-bottom/geothermal well samples, in agreement with previous 4He/3He data. This late-stage exhumation is associated to the onset of major Alpine glaciation triggering the Rhône valley carving at $\sim$1 Ma. Apatite track length measurements suggest that the well samples have been affected by recent hydrothermal activity. This agrees well with the present-day observation of high geothermal activity below the Rhône valley floor, whose origin has been primarily linked to structural inheritance (Simplon-Rhône extensional fault system). Our thermochronology data helps to put constrain on the onset timing of this geothermal activity, which we propose to be concordant with the onset of major alpine glaciations, glacial erosion and bedrock-fracture development promoting localized fluid circulation and hydrothermal activity below the Rhône valley floor.